Ultra High Temperature, Ultra Short Time Surface Pasteurization of Meat

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ABSTRACT

A novel device killed with steam most surface organisms on fresh meat without cooking the surface. Treatment for 25 milliseconds with 145°C thermally saturated steam in the absence of air, followed by vacuum cooling, produced a 4 log kill of an applied dose of 10^7 *L. inocua* on raw fresh chicken meat. Similar results were achieved on fresh beef and pork. Total cycle time <1 sec suggested that a single unit could serve a broiler processing line, after the chill tank, and before the clean cut-up line.

Key Words: meat, poultry, surface pasteurization, vacuum cooling

INTRODUCTION

VERY RAPID SURFACE HEATING and cooling of meat surfaces has been achieved, using steam and vacuum. This may be useful because the toxic microorganisms of intact meat are usually on its surface (Gill and Penney, 1977). This is true of enterobacteria, such as *Salmonella*, whose origin is the GI tract of living animals (Bailey et al., 1990). Removal of these bacteria with water has been extremely difficult (Lillard et al., 1987; Lillard, 1990, 1994). Rapid heating was done with thermally saturated steam in the absence of air. Cooling was done by evaporating into vacuum the condensate formed during the heating. The objective was to surface pasteurize meat without producing a cooked appearance on its surface (Morgan, 1994).

The original premise was that much less heat would be needed to kill organisms on a surface, than to cook that surface, due to the much higher activation energy of cooking, as compared to killing (Harper, 1976). Hence killing without cooking would depend on the rapidity of both heating and subsequent cooling. The most rapid mode of heat exchange is known to be condensing vapor or evaporating liquid, both at the boiling temperature, in the absence of interfering gas (Minkowycz and Sparrow, 1966). In the case of steam, the huge latent heat of water makes the surface heating rate uniquely high (Perry and Chilton, 1974). Furthermore, only gas treatment could provide a uniform effect over a complex surface, rough on a microscopic scale, such as an eviscerated chicken carcass (Bechtel, 1986).

For these reasons, a small device was built to treat meat with vacuum, flush with steam, treat with steam, and cool with vacuum (Morgan et al., 1995). Feasibility tests showed that 4-log reduction of bacteria on a chicken meat surface could be achieved without cooking that surface, using 145°C steam for 25 millisec. Our objective was to test different surfaces, and different previous treatments for effects on kill. For the vacuum, minimum times were measured; and for the steam, different flushes, treatment times, pressures, and degrees of thermal saturation were tested.

MATERIALS & METHODS

A PROCESS WAS DEVELOPED which consisted of four steps. First, the air around the meat was removed. Second, the meat was flushed clear of adsorbed gas with low temperature steam. Third, the meat was surface heated by pure, thermally saturated steam. Fourth, the meat was evaporatively cooled by exposure to vacuum (Fig. 1). The device consisted of a stainless steel stator, inside of which there was a stainless cylindrical rotor, 150 mm long and 150 mm in diameter. A programmable servo-drive motor (Allen Bradley, Milwaukee), was provided to turn the rotor rapidly around its horizontal axis, stopping at precisely determined angular positions. The servo-drive could exert 50 joules of torque, so that high acceleration and braking rates were possible. Into the cylindrical surface of the rotor, a treatment chamber was milled to the depth of 75 mm. The chamber was oval in the tangential plane, 25 mm along the curved surface, and 75 mm wide. The chamber had a rounded bottom.

The stator provided clockwise an opening to air, then to vacuum, then to low pressure steam, then again to vacuum, then to high pressure steam, then again to vacuum, and finally back to air. The alternating vacuum and steam ports were symmetrical so that the radial forces on the rotor were largely balanced. Each of the stator ports was connected to the rotor by elliptical PEEK (polyetheretherketone) seals, notched square in cross section, which was held against the rotor by compressed O-rings in the stator.

The angular displacements between stator openings, relative to the angle subtended by the top of the rotor treatment chamber, was such that each opening was closed off from the next during rotation. However, the displacement between the first vacuum and the low pressure steam was such that a flush of low pressure steam could flow through openings 1 mm wide, from the steam into the chamber, and from the chamber into the vacuum as the chamber passed from vacuum to steam.

A 200L tank was provided with electric immersion heating to serve as a steam generator. The steam passed directly to the high pressure port of the rotor, or through a pressure-reducing valve to the low pressure port. Steam quality was assured by using degassed feed water, and by ample steam venting before and during use. These measures to create steam free of air were taken because of a previous observation of steam injection heating by high speed photography (Morgan and Carlson, 1960). In that work, the duration of steam bubbles in water was found to depend mainly on the quantity of air in the water and in the steam.

Another 200L tank served as a vacuum receiver. It contained a refrigerated condenser. A two-stage piston pump evacuated the receiver to about 20 millibars, absolute. Both tanks were connected to the stator through the shortest possible lengths of 50 mm diameter tubing.

Meat

Fresh chicken broilers were purchased daily from a local market. Small samples, about 5g, 10 mm by 10 mm, 50 mm long, were cut raw from the breast muscle, one side being the intact epimysium. Similarly sized samples were cut from raw choice lean beef chuck muscle, and from raw lean Boston butt pork.

The extent of cooking was judged by eye immediately after treatment. For fresh cuts, there was little ambiguity in recognizing cooked changes. When samples had dried due to prolonged vacuum treatment, cooking was slightly harder to judge. The onset of cooking was marked by the whitening of only the very thin parts of the sample. For this reason, instrumental color analysis of whole samples was considered unreliable.

Microbiology

A nonpathogenic corynebacterium, *Listeria inocua*, a nonproteolytic, Gram-positive organism, was used as a model for the array of wild contaminating pathogenic organisms, particularly for *L. monocytogenes* (Foegeding and Stanley, 1991). *L. inocua*, SA3-VT, a 4 μm rod, has about the same size, body shape, and thermal resistance as do many enterobacteria. The inoculum was freshly grown in 100 mL of BHI broth with 300 mg glucose at 28°C for 18–24 hr before each test.

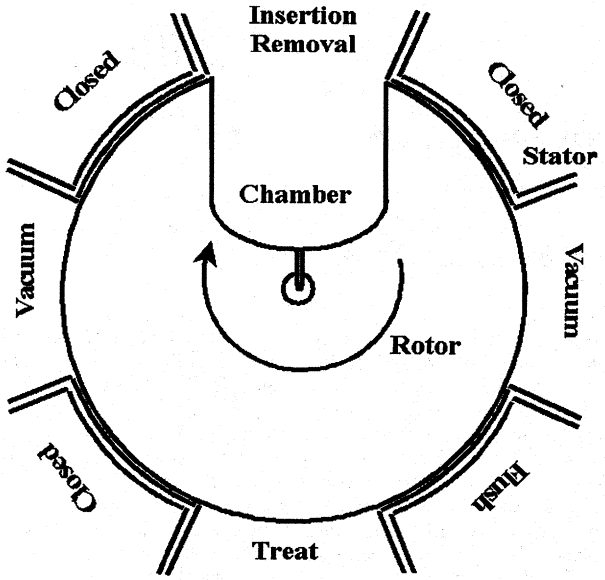

Fig. 1—Steps of the surface pasteurization process.

About 10^7 organisms were applied to each piece at room temperature. Inoculum (10 μL) was dripped onto the epimysal surface, and allowed to dry at ambient temperature inside a biological hood. After treatment, the meat sample was homogenized in a stomacher bag (Seward, London) with 9.9 mL 0.1% peptone at room temperature. After homogenizing, dilutions in peptone were plated spirally onto tryptose agar and incubated at 37°C for 24 hr before colony forming units (cfu) were counted with a Bacteria Colony Counter, model 500A (Spiral Systems Instruments, Cincinnati).

Inoculated and uninoculated untreated controls were counted the same way for each run. Inoculated and over treated (140°C for 2 sec) controls were also counted. Control counts were made on a *Listeria*-specific medium, modified Vogel Johnson agar (Buchanan et al., 1989), as well as on the more general medium, tryptose agar. Very little difference was found because the meats usually had low initial counts of spoilage organisms. Overtreated controls were usually sterile. Kills were reported as the difference in log numbers of organisms between treated and untreated samples.

Treatments

To retain the meat within the treatment chamber, meat samples were first inserted into mesh cylinders which fit inside the chamber. The cylinders were woven from 0.8 mm diameter stainless steel wire, with square openings 3 mm on centers. Such a mesh is 50% open. We found that the mesh obscured parts of the meat surface from the steam. When the heat-cool treatment was repeated several times this shadowing effect largely disappeared. This was due to the fact that the meat samples were loose within the mesh cylinders so that the acceleration of the chamber moved the meat around somewhat. The repeated treatment usually did not result in cooking, because each heating event was followed by a cooling event. For this reason, the treatment times reported are those for a single heating, not the accumulated times of repetitions. The shadowing artifact should disappear with larger samples.

The actual times of treatment were observed by means of digital video recording, using the 1000 frames/sec capability of the EktaPro motion analyzer, model 100HRC (Eastman Kodak, San Diego). Time was measured from first inrush of high pressure steam to the treatment chamber until the first exhaust of this steam into vacuum. The reported exposure times were accurate to ± 2 millisec.

RESULTS & DISCUSSION

THE TIME FOR SURFACE COOKING to begin depends on the factors affecting rate of heat transfer to the meat. The time for cooking to begin under the best conditions found for chicken broiler meat pieces are shown (Table 1).

Table 1—Time for cooking to begin in chicken broiler meat pieces at various temperatures

Steam temperature (°C)	Time (millisec)
100	1000
113	330
119	230
128	150
132	135
143	80
150	55
162	26

Effect of vacuum time

When vacuum was not applied, every treatment condition resulted in a cooked appearance, however brief the steam treatment. Therefore, 20 millibar vacuum was applied for varying times to find the minimum time needed with different steam treatments. This vacuum pressure was chosen because it is the pressure at which water boils at room temperature, hence a water cooled condenser could have been used in the vacuum receiver instead of the refrigerated condenser. Samples were exposed to vacuum before treatment for deaeration and after treatment for evaporative cooling. Equal times were used for deaeration and for cooling. Individual vacuum exposure times were expressed in millisec and results showed that about 1 sec vacuum was enough (Table 2).

Effect of superheat

A restriction was inserted into the high pressure steam duct close to the treatment chamber. This restriction was 25 mm long. Its open area was only 15% of the cross sectional area of the open steam duct. The result was an adiabatic expansion of steam just as it reached the meat. The effect was to expose the meat first to superheated steam, rather than thermally saturated steam. Bacterial kills with or without the superheat were compared (Table 3). All treatments were 48 millisec.

This showed that the effect of superheat was to decrease the rate of heating the meat surface. The effect increased with steam temperature. The reduced heat transfer rate from superheated steam compared with transfer from thermally saturated steam was a consequence of condensing heat transfer compared to convective heat transfer. The inference is that thermally saturated steam should be applied to the meat through unobstructed ducts which are as wide and as short as possible.

Effect of steam flush

Vacuum treatment before steam heating removed 98% of the air around the meat. To remove most of the remaining 2%, the evacuated chamber should be flushed by low temperature steam, free from air. Such flushing steam would expand into the evacuated treatment chamber, swirl around the meat, and flow out into the vacuum receiver, carrying with it the remaining air. To observe this effect, steam flushes of varying duration under identical conditions were contrasted (Table 4). The observed log kills without cooking for two steam treatment temperatures, for 210 millisec were compared.

These results showed that the beneficial effect of steam flush on kill without cooking was important, and its effect increased with increasing treatment temperature. At the higher temperatures, it was important to use a low pressure steam source for flushing, rather than the higher pressure steam intended for the treatment itself. For the higher temperature treatments, the flushing steam was derived from a low pressure tank at 104°C which was supplied from the high pressure tank through a reducing valve. A flush by originally higher pressure steam may retain enough superheat to warm the meat prematurely as the steam expands into the evacuated chamber. Otherwise, the temperature of the source of flushing steam is irrelevant.

Table 2—Effect of vacuum time on chicken meat treated for 210 millisec

Vacuum duration	Steam temp (°C)	Effect on chicken
50 millisec	143	cooked
550	143	slightly cooked
1050	143	uncooked
50	127	cooked
550	127	slightly cooked
1050	127	uncooked

Table 3—Effect of superheat on log kill by steam for 48 millisec

Steam temp (°C)	Kill with superheat (log reduction)	Kill without superheat (log reduction)
127	1.3	2.2
138	2.0	2.8
149	2.1	3.1

Table 4—Effect of flush time on kill by steam treatment for 210 millisec

Duration of flush (millisec)	Steam temp (°C)	Log reduction
80	116	1.2
500	116	1.3
1000	116	2.2
80	127	2.1
500	127	2.7
1000	127	3.1

Effect of steam temperature on kill

Treatments were compared for fresh chicken broiler meat pieces, each surface inoculated with about 10^7 *L . inocua* (Table 5). For one treatment time, 26 millisec, the effect of steam temperature on log kill without cooking is shown. Vacuum times were held at 1 sec, the vacuum pressure being 20 millibars. Flush times were held at 135 millisec, using 104°C steam as a source of the flush. Many of the treatments were repeated, with cooling after each heating, so as to reduce the shadowing effect of the mesh sample cage. Kills reported were means of three repetitions of each condition. Reproducibility of log kills were ± 0.6 with no detectable dependence of variance on kill level.

This showed that log kill increases with steam temperature to about 138°C and then decreases, when exerted for 26 millisec. The decreased kill above 138°C seemed to reflect the narrowing of the interval between killing and cooking heat doses. At shorter exposure times, shadowing by the mesh was more pronounced, which reduced the proportion of organisms killed. At the more tolerant temperature of 138°C, the surface could be more carefully treated with more repetitions, yielding the optimum kill for this exposure time. However, the number of repetitions did not correlate with kill. This conflicting effect could only be resolved by use of larger meat samples in a future prototype device.

Effect of surface

The nature of the surface had a strong effect on kill achieved with a particular heat dose. The log kill of *L. inocua* was compared on various surfaces when treated for 48 millisec with 121°C steam (Table 6).

These results are shown for comparison of surfaces; although slightly better results were obtained with chicken at 145°C at 25 millisec. The other meats would be cooked at that temperature. The kind of surface and its history both had strong effects on the kill for any particular time and temperature. However, this does not mean that only chicken could be adequately surface pasteurized. For other meats, the optimum conditions for kill without cooking must be separately determined. For example, there is evidence that both beef and pork could be treated at higher temperatures for shorter times to achieve higher kills without cooking when treated only on its usual fatty epimysal surface.

Table 5—Effect of steam temperature on log kill on fresh chicken meat for 26 millisec

Steam temp (°C)	Log kill
127	2.2
138	4.0
149	2.8
157	2.7

Table 6—Effect of various surfaces on kill with 121°C steam for 48 millisec

Surface	Log kill
Filter paper	6.3
Fresh chicken meat	4.0
Thawed frozen chicken meat	2.8
Thawed frozen chicken skin	2.4
Fresh lean beef	2.5
Fresh lean pork	1.9

CONCLUSIONS

MEAT CAN BE SURFACE PASTEURIZED without cooking the surface. The best treatment for chicken meat was 145°C steam for 25 millisec. This treatment must be preceded and followed by vacuum treatments, so that the total treatment time would be about 1 sec. This implies a rate of 3600 birds/hr/device. If chambers for multiple birds were designed, then capacities would be multiples of 3600. The next question to answer is how well can fresh whole eviscerated birds be surface pasteurized when they carry small spots of intense toxic contamination. The device used a rotor-stator developed to close the chamber, admit vacuum, steam flush, steam treat, vacuum cool, and open the chamber. Further work should involve a 200 mm diameter chamber, large enough for whole birds. This should be arranged so that opening and closing the chamber is independent of vacuum and steam flows.

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